

An aerial photograph of a campus in Berkeley, California. In the foreground, a large array of solar panels is visible on the right, and a green lawn with two golf carts is on the left. In the background, there are several buildings, palm trees, and a large mountain range under a clear blue sky.

Department of Energy Merit Review and Peer Evaluation

**Berkeley, California
May 19-22, 2003**

SunLine 3-year Development & Demonstration Program



SunLine - DOE Peer Review



Solar System Summary and Conclusions

Summary:

218 Siemens flat panels, 1744 sq.ft, 20 kW rated capacity

144 EcoEnergies tracking arrays, 432 sq.ft, 17 kW rated capacity

Trace DC to AC Inverter

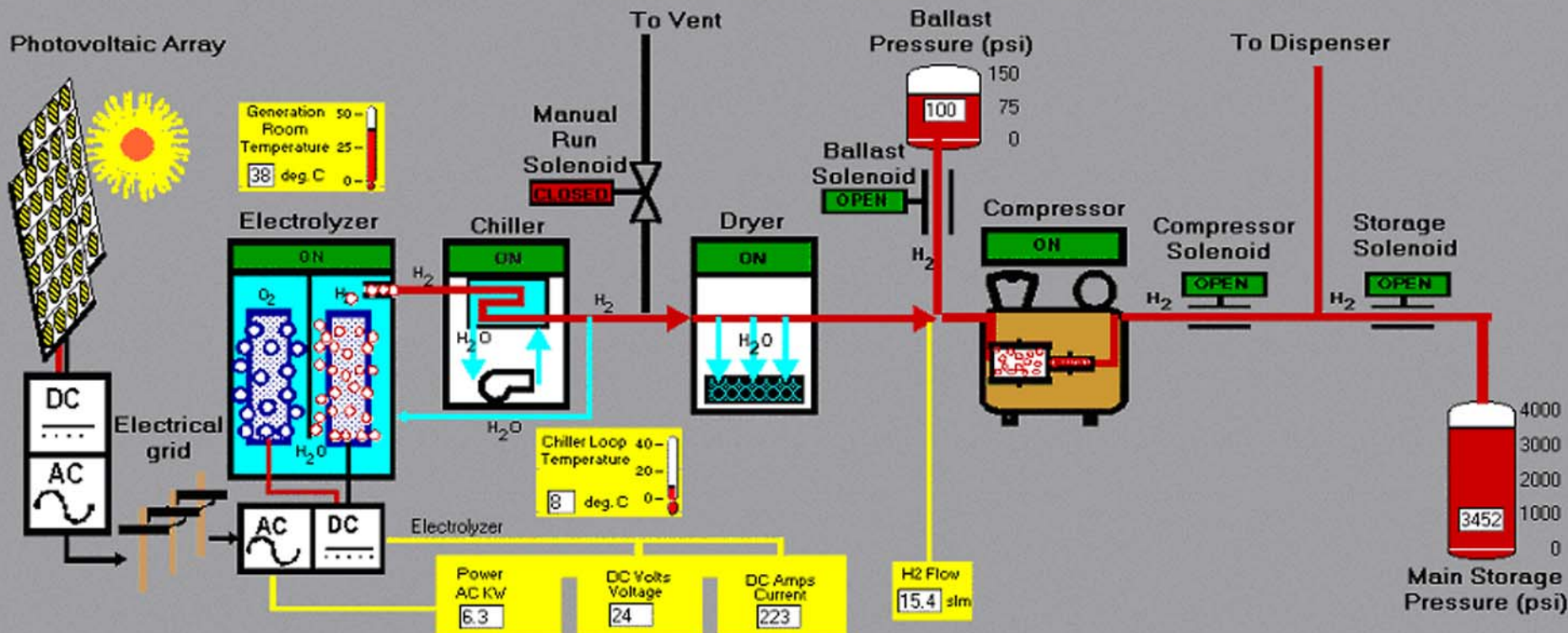
Conclusions:

System efficiency of 7%, impacted by heat and wind blown dust

15% production lost due to system faults and limited equipment reliability



Schatz Solar Hydrogen Generation Station



PROGRAM CONTROL

**SAFETIES
ENABLED**

PROGRAM RUNNING
(press to stop program)

PROGRAM STATUS

Iterations

16116

Operation mode

Normal Run

Time elapsed

0: 4:1.44

of writes
to file

1800

Current Fault Status

No Fault

Last Shutdown Fault

No Fault

DAILY TOTALS FOR 7/30/00

Hydrogen Production

811.0 Total Std
Liters

Electrolyzer Electrical
Consumption

5.1 Total kWh

Hours Operational

0.91 Compressor

1.06 Electrolyzer

Electrolyzer
Efficiencies

0.87 Faraday

1.01 Voltage

0.53 Electrolyzer

SERC/Teledyne System Conclusions

There is no substitute for instrumentation

Capital cost is quite high at \$110,000

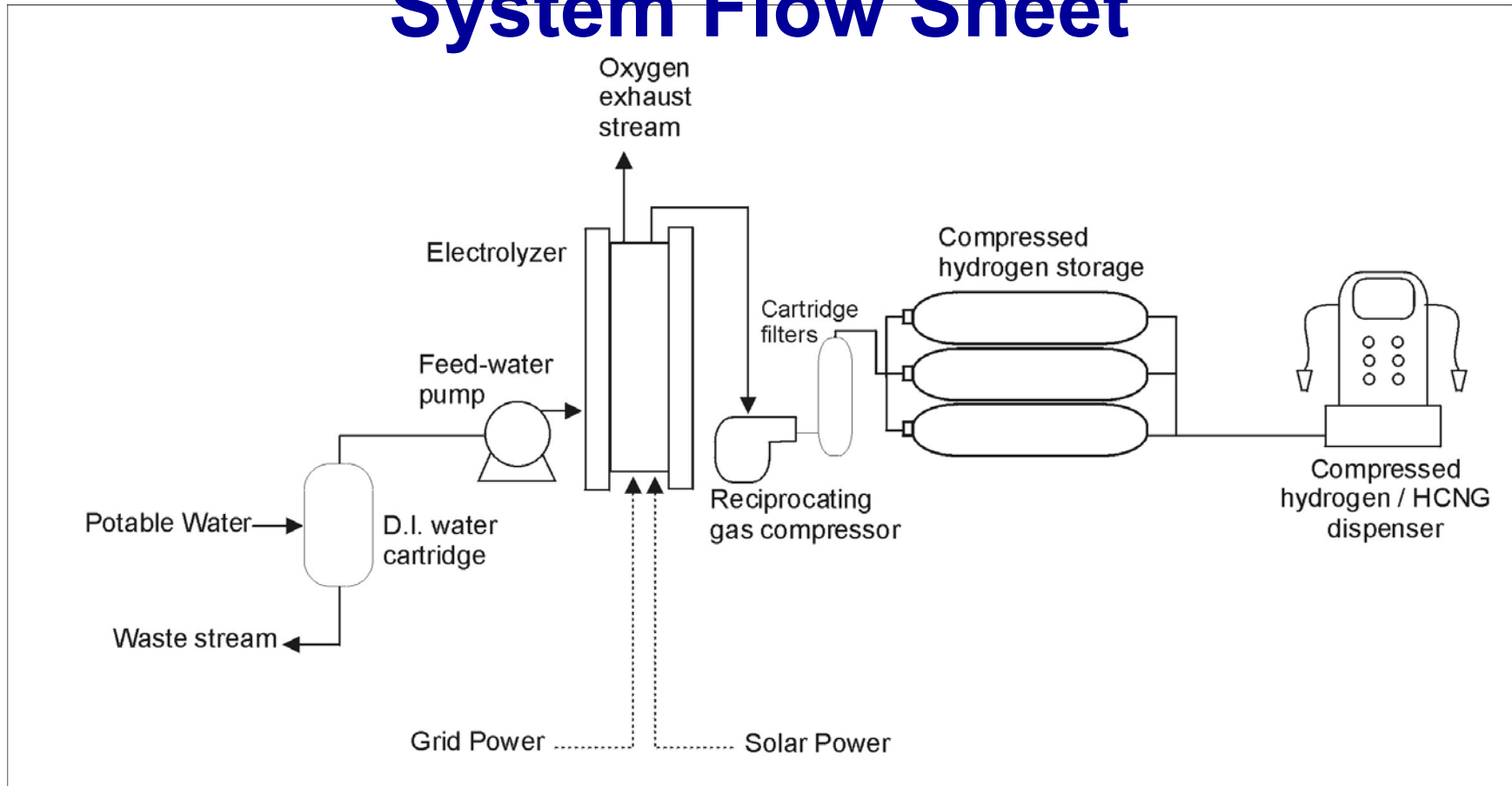
(Altus 20 at \$60,000, compression at \$25,000, dispensing at \$10,000 and installation at \$15,000.)

Operating costs reasonable at \$4 per gge, assuming electricity at 5 cents per kWh and no capital cost allocation

System very user-friendly and commercially available

Excellent platform for distributed generation - residential market - good fit in a two-car garage

Stuart Energy System Flow Sheet



Stuart Energy System Conclusions

There is no substitute for instrumentation

Capital cost reasonable at \$625,000

CFA 1350 at \$500,000, dispensing at \$60,000 and installation at \$65,000 (Site specific)

Operating costs reasonable at \$3.25 per gge, assuming electricity at 5 cents per kWh and no capital cost allocation

System requires 65 kWh/kg

System very user-friendly and commercially available

Excellent platform for distributed generation

Turn key services available

Hythane®/HCNG Program and Conclusions

Two Hythane® fueled Nova buses used in revenue service since 2000

No engine issues, fuel consumption equivalent to CNG

Improved engine and throttle response

45% less NOx (50% plus on newer engine platforms)

Justification for the development of a hydrogen infrastructure at transit facilities

HCNG can be a bridge to hydrogen!

**Hythane® fuel cost represents a 20% premium over CNG
(CNG at \$1.50 per gge and hydrogen at \$3 per gge)**

Ballard Fuel Cell Bus Program and Conclusions

13-month demonstration program

Bus traveled 8,963 miles in simulated revenue service

**Last significant trip October 2001 from Fontana, CA to
Las Vegas (275 miles)**

**Fuel consumption of 8.9 miles per gge is 2.5 times better than
conventional CNG bus**

Lessons learned applied to P-5 cell stack and Citarro bus

Bus still in use at SunLine for VIP use and demonstrations

**Cost of recently purchased FC bus is \$3.1 million plus \$400k
for extended warranty**

Training Program

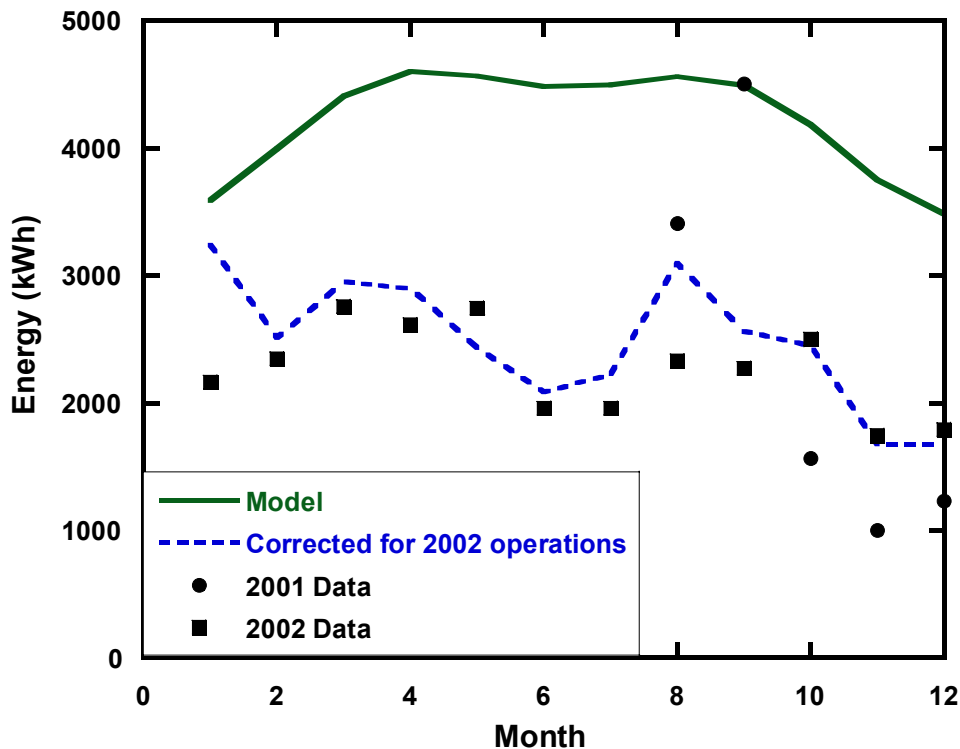


Lessons Learned

Photovoltaic collector simulation



Comparison to SunLine PV Data

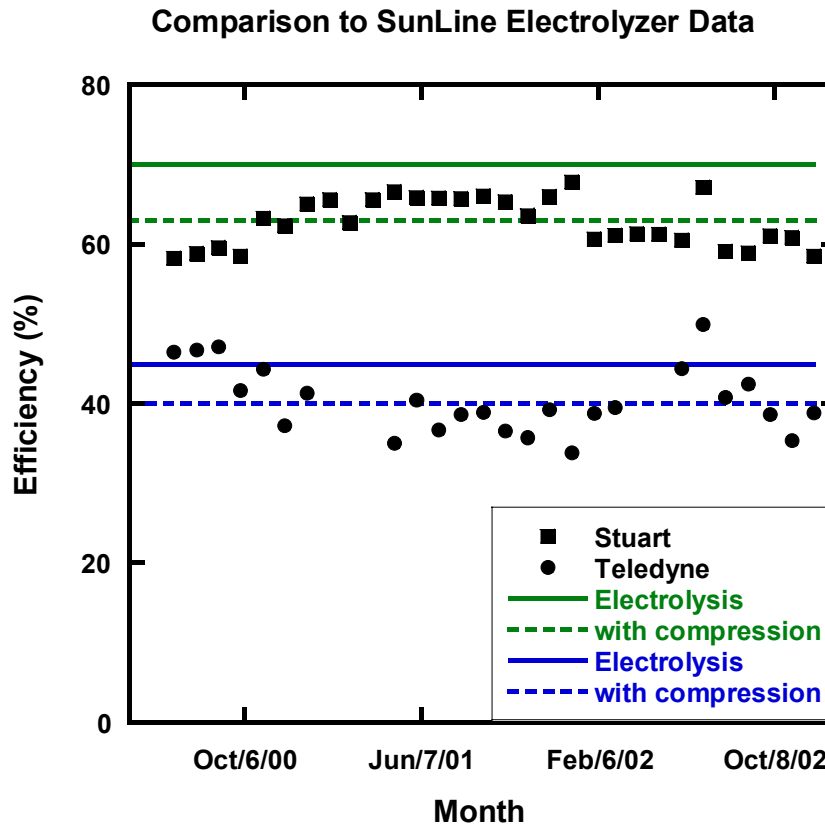


- **Model simulation**
 - Run yearly variation
 - Integrate daily collection
 - Sum monthly to compare to SunLine data
- **Solar radiation model**
 - Analytic function of longitude, latitude, altitude
- **PV panel model**
 - Area = 360 m², slope 23°
 - Adjust solar-electric conversion efficiency = 7 %
- **Correct monthly sums to SunLine's operations**
 - Operating days / month
 - Sunny days / month



Lessons Learned *continued*

Electrolyzer Simulation



Model comparison

- Electrolyzer + compressor to compare with SunLine data
- Estimate efficiency of electrolysis step to match average H₂ delivery efficiency

SunLine electrolyzers:

- Stuart Energy (Phase 3 unit)
 - Low-p cell output (1 psi)
 - Compression: 4-stages at 50% efficiency to 5000 psi
- Teledyne Energy Systems
 - High-p cell output (100 psi)
 - Higher purity H₂ supply
 - Compression: 2 stages at 20% efficiency to 3600 psi



Lessons Learned *continued*

Hydrogen safety and instrumentation requirements:

There is no substitute for instrumentation for diagnostics

Station development:

Codes and standards, permitting issues and requirements

Education and outreach critical

Advances in hydrogen production technology:

Significant advances in the last few years with systems getting more efficient and user-friendly

PLC control, data acquisition and remote access possible with web access or PC anywhere

Lessons Learned *continued*

Applications:

CNG engines run very well on HCNG blends consisting of 20% hydrogen with changes limited to engine calibration, and they can provide a demand for hydrogen production

Internal combustion engines may provide a platform for hydrogen as fuel cells are being developed and slowly introduced to the transportation and distributed power generation markets

Hydrogen fueled power generation may be required in the early stages with the deployment of natural gas reformers to address imbalances between supply and demand

Recommendations

There are no substitutes for:

Experimental design

DOE should provide support to all projects in this area

DOE labs should be drafted to provide in-depth technical support to industry

Instrumentation and data acquisition

Funds should be allocated specifically to this activity

Comprehensive comparable data is required if we are going to get an accurate picture of systems and technologies and share lessons learned.

Recommendations *continued*

Internal combustion engines:

There is a need for a consensus that comprehensive R&D with HCNG and hydrogen fueled ICE hybrids is required to provide a bridge to fuel cell technology, justify the development of a hydrogen infrastructure, and test various technologies

Insurance industry:

An education and outreach program to the insurance industry is required to aid industry in assessing the risks involved with hydrogen and fuel cell technology

Technology transfer:

Early adopters should be tasked to share lessons and assist with projects under development

Outreach, Collaboration and Partnerships



Future Programs



Future continued

